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AVERAGE YARDING DISTANCE ON IRREGULAR-SHAPED TIMBER HARVEST SETTINGS

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ABSTRACT

Average yarding distance and area are determined for irregular harvest settings using the method of moments and a desk-top programable calculator with digitizer. The method, fast and accurate, should be useful to those involved in timber sale layout and appraisal.

Keywords: Forest cutting systems, mathematical instruments, digitizer.

INTRODUCTION

The trend to natural-shaped cutting units *(6, 7)* poses new problems in rapidly and accurately determining area and average yarding distance. Easy methods for determining the average yarding distance and area are available for simple shapes of right triangles, rectangles, and circular arcs. The average yarding distance and area of irregular shapes can be determined by methods of numerical integration, a manual procedure much too time consuming for practical use.

This research note presents a simple and accurate technique for obtaining area and average yarding distance of a setting of any shape using a programable calculator with a peripheral digitizer. The digitizer transfers the necessary information from the map to the calculator which is programed to compute area and average yarding distance *(AYD)*.

APPLICATIONS

The major applications of the method presented in this note are in forest engineering design, sale layout, and sale appraisal. All three require cutting unit area and *AYD* as part of their functional input into the timber harvest planning process.

The forest engineer is concerned with determining equipment needs and physical design data for each harvest unit. Area and *AYD* are necessary to determine logging costs and are used in evaluating spar locations, road locations, and outer yarding limits. In addition, this information should be used to provide landscape architects with the physical limitations of the harvest system consistent with esthetic requirements, allowing both disciplines to maintain high standards of quality.

Sale layout and appraisal are concerned with stumpage costs, volumes per acre, adherence to guidelines established by the logging system selected, and landscape esthetics. Costs, timber volumes, and esthetics require information on *AYD* and area.

In addition, the method presented in this note is useful for determining areas of logged units, rock outcrops, existing right-of-way, and inaccessible timber. All are important elements of the timber harvest plan, which can be obtained without changing methods or procedures.

PROBLEM FORMULATION

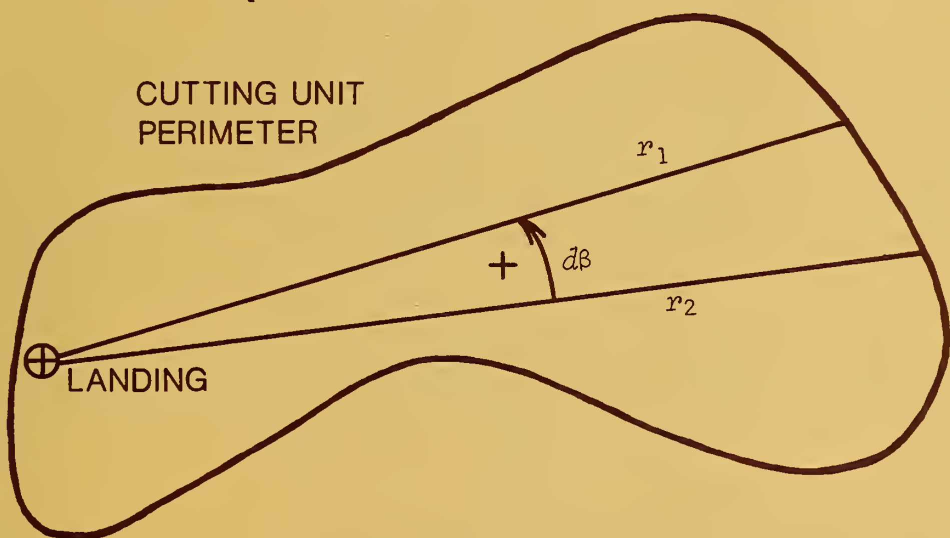
Matthews *(3)* used the method of equal areas to calculate *AYD* as early as 1942. This method was used for many years and is still used by some today. Lysons and Mann *(2)* showed that for a circular cutting unit, the method of equal areas gave an incorrect result. Their analysis showed that, in general, the *AYD* is given by

$$AYD = \frac{\int y da}{\int dA} = \frac{\text{First moment of area}}{\text{Area}} \tag{1}$$

Equation 1 can be used to calculate the *AYD* for other geometric shapes.

Suddarth *(4)* presents *AYD* for right triangles, rectangles, and circular arcs. He also presented a method of calculating *AYD* of a composite area for which the respective *AYD*'s are known. For complex areas, Suddarth recommends numerical integration.

The programable calculator-digitizer method presented in this note uses an algorithm based on equation 1 as follows:



$$dA = 1/2\ r^2\ d\beta \simeq 1/2 \left(\frac{r_1 + r_2}{2}\right)^2 d\beta$$

$$dM = (2/3\ r)\ dA = 1/3\ r^3\ d\beta \simeq 1/3 \left(\frac{r_1 + r_2}{2}\right)^3 d\beta$$

$$M = \Sigma_A\ dM$$

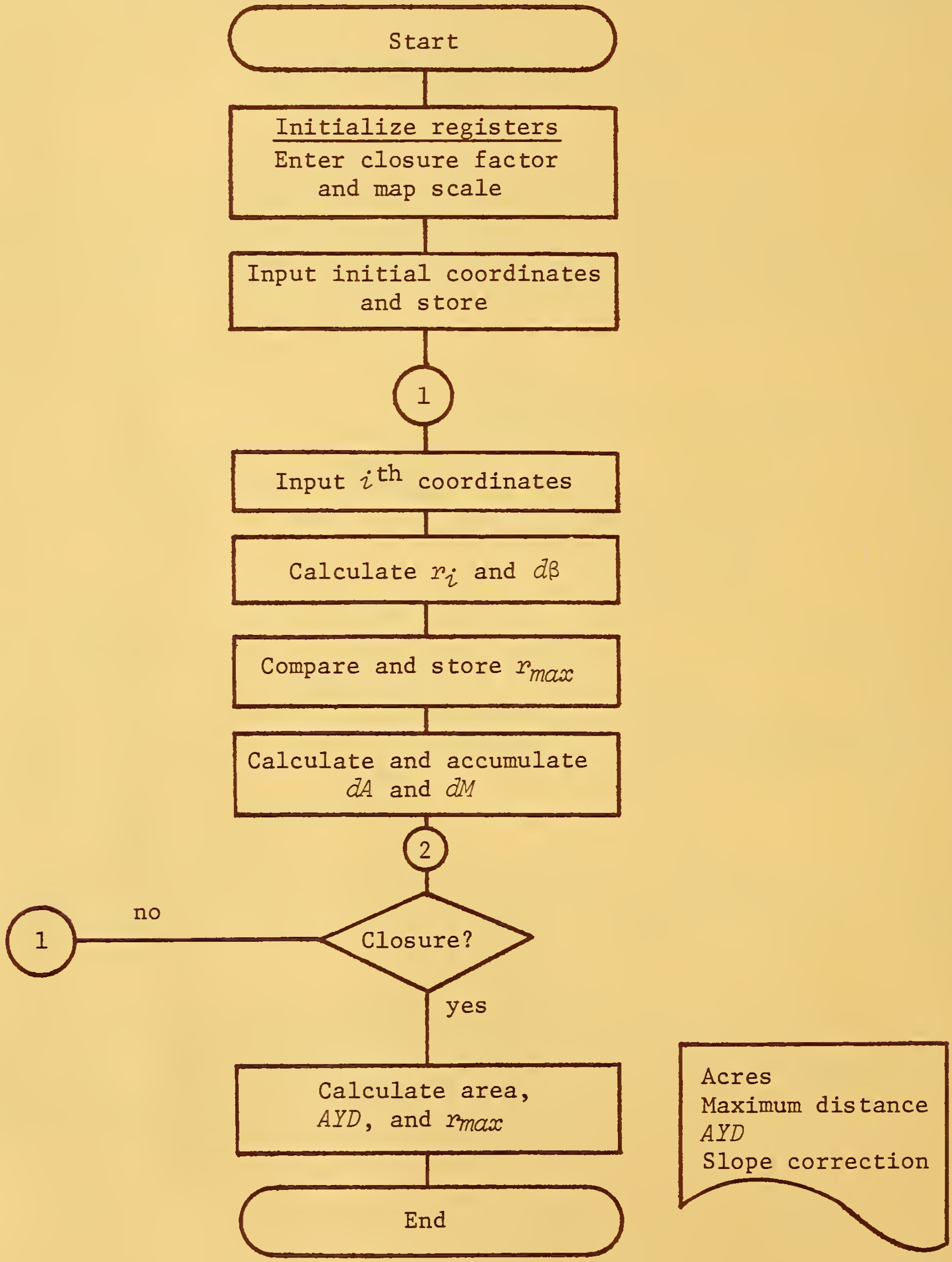
$$A = \Sigma_A\ dA$$

and

$$AYD = \frac{M}{A}$$

GENERAL LOGIC

The digitizer provides continuous x and y coordinate data to the calculator. The calculator converts this data to angles (β) and distances (r) used in computing incremental areas (dA) and moments (dM). The generalized logic is illustrated in the following flow diagram:



PREPARATION OF DATA

Procedures for planning sales, sale layout, and sale appraisal are documented in the Forest Service Manual *(5)*, research publications *(1)*, and in standard timber harvesting references. No attempt will be made in this note to present the details of sale design.

The method presented here requires that the cutting unit be laid out on a planimetric map of known scale. If slope corrections are required, then average slope must be determined or layout made on a topographic map. The cutting unit perimeter should be located in accordance with sale requirements and the location of the landings determined.

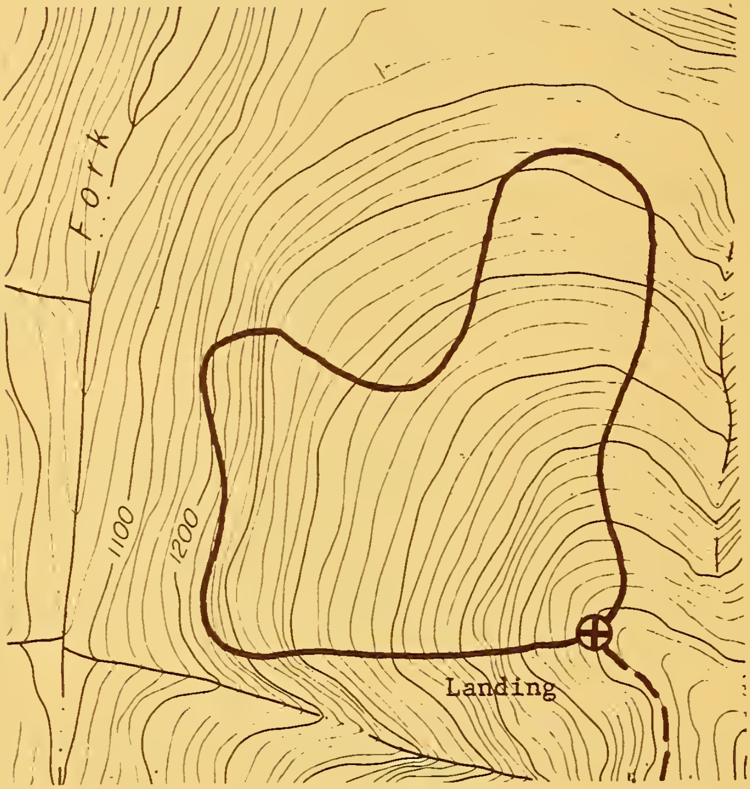
EXAMPLE DATA

Figures 1, 2, and 3 illustrate examples of timber harvest settings overlaid on topographic sections and the printer output from the programable calculator. Average time to set up and digitize each unit, including output, was 50 seconds.

Figures 1 and 2 are small, somewhat irregularly shaped units typical of short reach grapple-yarding methods. Figure 3 is a very irregular, relatively large setting, with an area of leave timber between the landing and the maximum corner. Irregular-shaped units, such as shown in figure 3, are visually more pleasing when viewed as part of the background. In contrast, an equivalent area rectangular cutting unit would appear larger, with its harsh, straight lines, and hence more objectionable.

Printer output for each unit displays the acreage of the unit, the maximum horizontal yarding distance, the average horizontal yarding distance, and the *AYD* corrected for slope.

Figure 1.--Small, irregular-shaped cutting unit.



Horizontal scale: 1 inch = 200 feet
Vertical scale: 20 feet
Average slope = 100 percent

Acres	3.81
Maximum distance	518.19 feet
AYD	296.84 feet
Slope correction	420.00 feet

Figure 2.--Small, irregular-shaped cutting unit.

Horizontal scale: 1 inch = 400 feet
Vertical scale: 20 feet
Average slope = 50 percent

Acres	9.70
Maximum distance	926.65 feet
AYD	460.16 feet
Slope correction	514.00 feet

Figure 3.--Large, irregular-shaped cutting unit.

Horizontal scale: 1 inch = 500 feet
Vertical scale: 20 feet
Average slope = 40 percent

Acres	50.00
Maximum distance	1,850.00 feet
AYD	1,011.83 feet
Slope correction	1,090.00 feet

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OPERATING PROCEDURES

The method presented in this note was developed using a Hewlett-Packard[1/] 9100B Programable Calculator, 9107A Digitizer, and 9120A Printer. The following operating procedures and program are for the above equipment.

1. Digitizer: On
2. Calculator: On
3. Set: Radians
4. Set: Fixed
5. Decimal Wheel at 2
6. Printer on x
7. Enter program A at + (0)(0)
8. Enter program B at - (0)(0)
9. Press: End, Continue
10. Enter E (automatic closure in x register) Note: Program assumes E = 0.05 unless changed.
11. Press: Continue
12. Enter: Horizontal map scale in x register
13. Press: Continue
14. Move cursor to initial origin
15. Press: $\boxed{0}$ on cursor
16. Move cursor to landing
17. Press: $\boxed{C}$ on cursor
18. Trace cutting unit perimeter in counterclockwise direction until audible signal is heard
19. Press: $\boxed{C}$ on cursor
20. Printer will display: Acres
Max. Yarding Dist. (Hor.)
AYD (Hor.)
21. Enter: Average slope as a decimal (60 percent = .60) in x register
22. Press: Continue
23. Printer will display: AYD (corrected for slope)
24. For new setting, re-enter program A at + (0)(0) (Program A is destructive in register 0) and return to instruction 9.

1/ *The use of trade, firm, or corporation names in this publication is not an official endorsement or approval by the U.S. Department of Agriculture of any product to the exclusion of others which may be suitable.*

Title Average Yarding Distance and Area of Irregular Setting

Step	Key	Code	Display x	Display y	Display z
00	CLR	20	0	0	0
01	.	21			
02	0	00			
03	5	05			
04	STP	41	ε		
05	XTO	23			
06	9	11			
07	STP	41	Scale		
08	XTO	23			
09	-	34			
0a	b	14			
0b	CNT	47			
0c	CNT	47			
0d	CNT	47			
10	CLR	20	0	0	
11	XTO	23			
12	0	00			
13	FMT	42			
14	.	21	X_1	Y_1	
15	XTO	23			
16	a	13			
17	YTO	40			
18	b	14			
19	FMT	42			
1a	.	21	X_2	Y_2	
1b	UP	27			
1c	a	13	X_1	X_2	Y_2
1d	-	34			
20	b	14			
21	RUP	22			
22	XEY	30			
23	-	34			
24	DN	25			
25	XEY	30	ΔX_2	ΔY_2	
26	POL	62	r_2	β_2	
27	XTO	23			
28	d	17			
29	XTO	23			
2a	0	00			
2b	YTO	40			
2c	c	16			
2d	FMT	42			
30	.	21	X_i	Y_i	
31	UP	27			
32	a	13			
33	-	34			
34	b	14			
35	RUP	22			
36	XEY	30			
37	-	34			
38	DN	25			
39	XEY	30	ΔX_i	ΔY_i	
3a	POL	62	r_i	β_i	
3b	XTO	23			
3c	-	34			
3d	f	15			
40	YTO	40			
41	-	34			
42	e	12			
43	XFR	67			
44	0	00			
45	UP	27		STORE	
46	XFR	67		r max	
47	-	34			
48	f	15			
49	X<Y	52			
4a	5	05			
4b	0	00			
4c	XTO	23			
4d	0	00			
50	XFR	67			
51	-	34			
52	e	12			
53	UP	27			
54	XFR	67			
55	-	34			
56	f	15			
57	UP	27			
58	d	17			
59	YTO	40			
5a	d	17			
5b	+	33			
5c	2	02			
5d	÷	35			
60	c	16			
61	RUP	22			
62	XEY	30			
63	YTO	40			
64	c	16			
65	-	34			
66	DN	25			
67	XTO	23			
68	-	34			
69	c	16			
6a	YTO	40			
6b	-	34			
6c	d	17			
6d	UP	27			
70	UP	27			
71	|Y|	55			
72	5	05			
73	X>Y	53			
74	-	34			
75	1	01			
76	6	06			
77	GTO	44			
78	-	34			
79	0	00			
7a	0	00			
7b					
7c					
7d					

+	Storage
f	ΣdA
e	ΣdM
d	r (CURRENT r)
c	β_i
b	Y_i
a	X_i
9	ε
8	AYD (TEMP)
7	
6	
5	PROG A
4	
3	
2	
1	
0	Max r

Title Average Yarding Distance and Area of Irregular Setting (continued)

Step	Key	Code	Display x	Display y	Display z
00	DN	25			
01	π	56			
02	+	33			
03	+	33			
04	YTO	40			
05	-	34			
06	c	16			
07	|Y|	55			
08	5	05			
09	X>Y	53			
0a	-	34			
0b	1	01			
0c	6	06			
0d	DN	25			
10	π	56			
11	-	34			
12	-	34			
13	YTO	40			
14	-	34			
15	c	16			
16	XFR	67			
17	-	34			
18	d	17			
19	UP	27			
1a	XFR	67			
1b	-	34			
1c	c	16			
1d	UP	27			
20	2	02			
21	÷	35			
22	DN	25			
23	XEY	30			
24	X	36			
25	X	36	r	dA	r
26	UP	27			
27	DN	25			
28	X	36			
29	2	02			
2a	X	36			
2b	3	03			
2c	÷	35			
2d	DN	25			

Step	Key	Code	Display x	Display y	Display z
30	XEY	30	dA	dM	
31	AC+	60			
32	IFG	43			
33	5	05			
34	a	13			
35	XFR	67			
36	9	11			
37	UP	27			
38	d	17			
39	|Y|	55			
3a	X<Y	52			
3b	4	04			
3c	4	04			
3d	XEY	30			
40	CHS	32			
41	XTO	23			
42	9	11			
43	XEY	30			
44	XEY	30			
45	XFR	67			
46	9	11			
47	+	33			
48	CLX	37			
49	X>Y	53			
4a	5	05			
4b	2	02			
4c	GTO	44			
4d	+	33			
50	2	02			
51	d	17			
52	SFL	54			
53	b	14			
54	UP	27			
55	a	13			
56	GTO	44			
57	+	33			
58	3	03			
59	1	01			
5a	RCL	61			
5b	UP	27			
5c	5	05			
5d	RDN	31			

Step	Key	Code	Display x	Display y	Display z
60	÷	35	Ain^2	AYD	5
61	YTO	40			
62	+	33			
63	8	10			
64	X	36			
65	YTO	40			
66	-	34		STORE	
67	e	12		AREA &	
68	XTO	23		Mom (in)	
69	-	34			
6a	f	15			
6b	UP	27			
6c	XFR	67			
6d	+	33			
70	8	10	A	AYD	5
71	XEY	30			
72	FMT	42			
73	RDN	31			
74	PSE	57			
75	FMT	42	AUDIBLE		
76	RDN	31			
77	PSE	57			
78	FMT	42			
79	RDN	31			
7a	XFR	67			
7b	-	34			
7c	b	14			
7d	X	36			

Storage

	+	−
f	r_i	Final Area
e	β_i	Final Mom
d	r	
c	Area Ft.^{2}	
b	S_{map}	
a		
9		
8		
7		
6		PROG B
5		
4		
3		
2		
1		
0		

Title Average Yarding Distance and Area of Irregular Setting (continued)

Step	Key	Code	Display x	Display y	Display z
8 0	UP	27	S	S	AYD
1	X	36		S^2	
2	f	15	Ain^2		
3	X	36		Aft^2	
4	YTO	40		Aft^2	AYD
5	–	34			
6	c	16			
7	4	04			
8	3	03			
9	5	05			
a	6	06			
b	0	00			
c	÷	35		Ac	AYD
d	DN	25	Ac		
9 0	PNT	45			
1	XFR	67			
2	0	00	r_{max}		
3	YEX	24			
4	–	34			
5	b	14			
6	X	36			
7	DN	25			
8	PNT	45	r_{max}		
9	RDN	25			
a	PNT	45	AYD		
b	UP	27			
c	X	36			
d	UP	27			
a 0	STP	41	SLOPE		
1	X	36			
2	DN	25			
3	UP	27			
4	X	36			
5	DN	25			
6	+	33			
7	DN	25			
8	$\sqrt{x}$	76			
9	INT	64			
a	PNT	45	AYD	(CORR.)	
b	SPC	45			
c	SPC	45			
d	END	46			

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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